

A WRF-Chem Analysis of Flash Rates, Lightning-NO_x Production & Subsequent Trace Gas Chemistry of the 29-30 May 2012 Convective Event in Oklahoma during DC3



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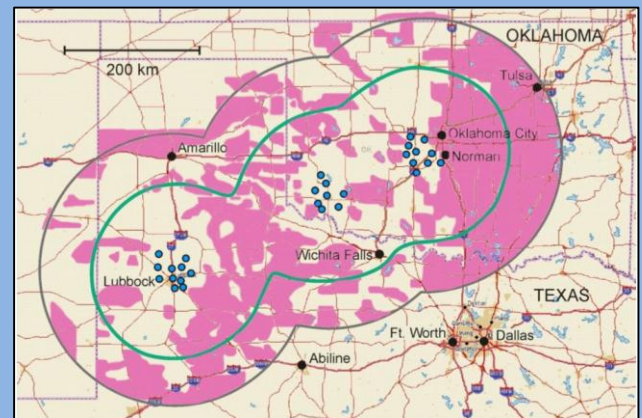
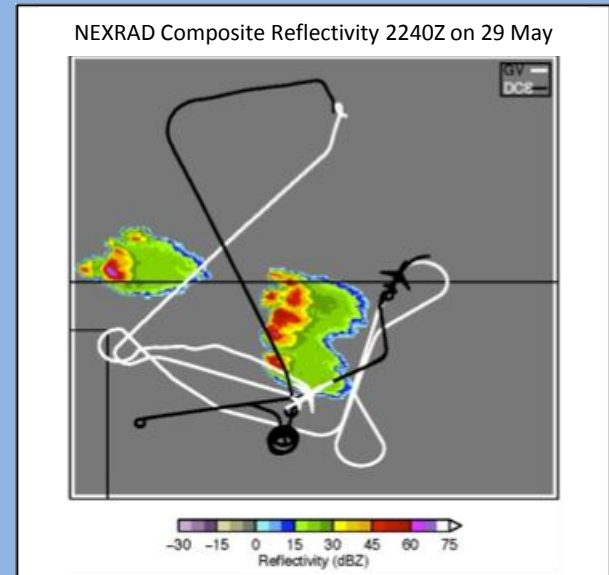
M. Barth & A. Weinheimer (NCAR), M. Bela (Univ. of CO), Y. Li & D. Allen (UMd), E. Bruning (Texas Tech Univ.), D. MacGorman (NOAA/NSSL), S. Rutledge, B. Basarab & B. Fuchs (CSU), I. Pollack & T. Ryerson (NOAA CSD), H. Huntrieser (Inst. of Atmos. Physics, Germany), & M. Biggerstaff (Univ. of OK)

Key Objectives

- Continuation of previous work, which compared flashes generated by various flash rate parameterization schemes (FRPSs) from the literature in a WRF-Chem model simulation with lightning observations:
 - Oklahoma Lightning Mapping Array (OK LMA)
 - National Lightning Detection Network (NLDN)
- Current work objectives:
 - Analyze distribution of observed and model-simulated trace gas species in storm inflow and outflow
 - Determine NO production scenario for IC and CG lightning-generated NO_x (LNO_x) scheme
 - Investigate additional FRPSs recently developed from DC3 radar and LMA data

Background

- Storm system developed ~21Z May 29 along KS/OK border and continued until 04Z May 30
- Aircraft sampled storm and its environment from 20Z May 29 to 01Z May 30
 - DC-8 focused on storm inflow & outflow
 - GV & Falcon concentrated on outflow
- Ground-based instrumentation included:
 - Dual-Doppler radar (NEXRAD level II regional)
 - Shared Mobile Atmospheric Research and Teaching Radar (SMART-Radar)
 - NLDN cloud-to-ground flash data
 - OK LMA flash initiation density data



Blue circles: LMA stations

Green outline: Extent of 3-D lightning mapping capability

Gray outline: Extent of 2-D lightning detection

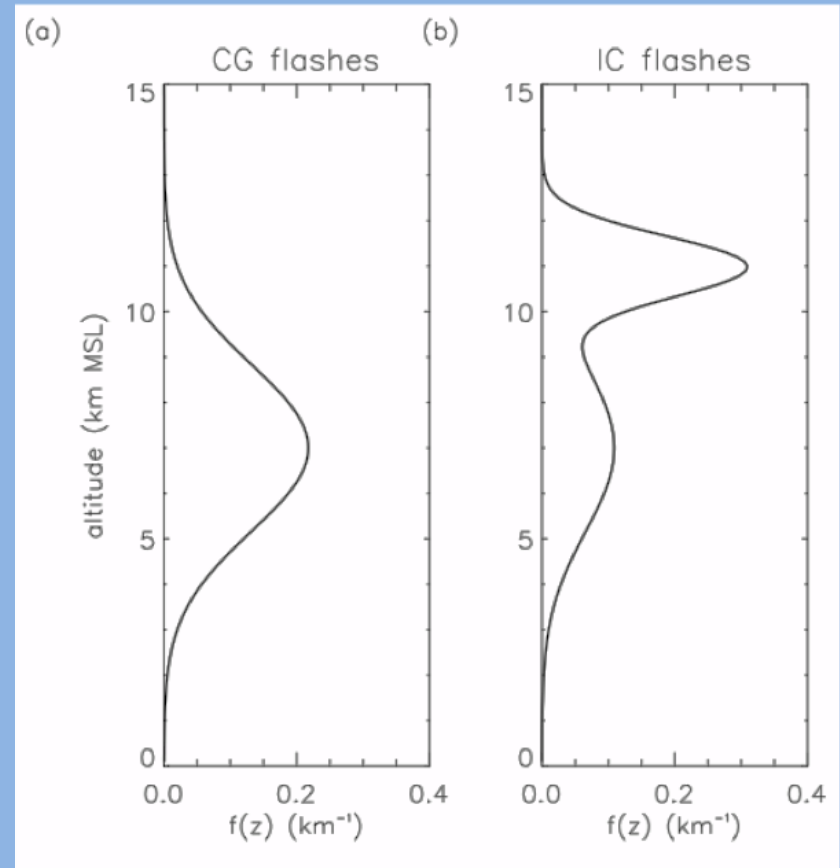
WRF-Chem Model V3.6.1

- Grid resolution: $dx = dy = 1\text{-km}$, $dz = 50\text{-}250\text{ m}$
- Initialized with 18Z NAM ANL (6-hr) for boundary conditions
- Lightning Data Assimilation (18-21Z)

Type of Scheme	Selection for Simulation
Microphysics	Morrison
Planetary boundary layer	Yonsei University (YSU)
Land surface	Noah
Radiation (short & longwave)	Rapid radiative transfer model for GCMs (RRTMG)
Photolysis	F-TUV
Trace gas chemistry	MOZART
Flash rate	<ul style="list-style-type: none">➤ Maximum vertical velocity (W_{\max}; <i>Price & Rind, 1992</i>)➤ Coarsely prescribed IC:CG ratios (<i>Bocchippio et al., 2001</i>)
LNO _x	DeCaria et al. (2000, 2005)

LNO_x Parameterization Scheme (DeCaria et al., 2005)

- Gaussian vertical distribution of IC (bimodal) and CG (single mode) NO production based on typical lightning flash channel distributions
- Lightning channels set to maximize at -15°C (CG and IC) and -45°C (IC)
- NO production can be specified
 - Mean value of 500 moles flash⁻¹ found in previous mid-latitude simulations (*Ott et al., 2010*)
- Horizontal placement of NO based on reflectivity ≥ 20 dBZ in each grid cell



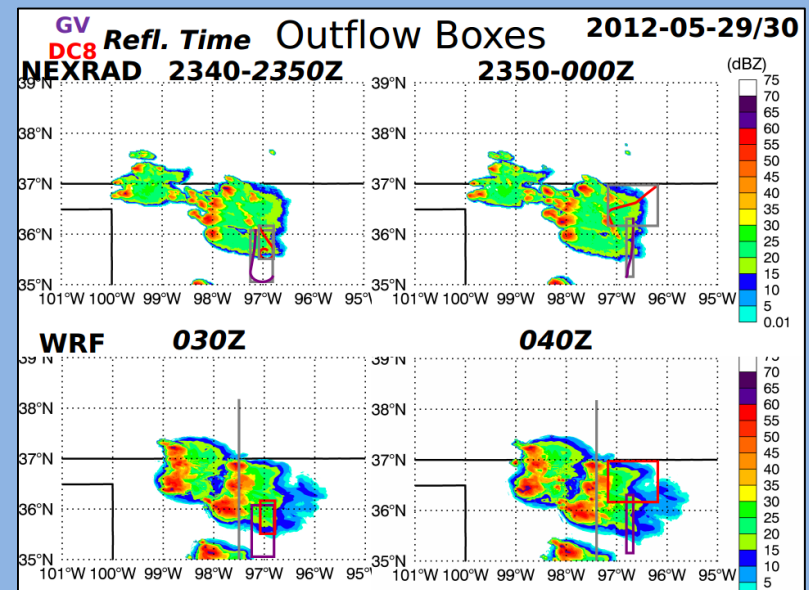
Methodology

- Used W_{\max} FRPS in model, since scaling factors provided reasonable results and we were interested in how aircraft observations compared with model-simulated trace gases:

- Find W_{\max} per processor (17 km x 19 km) and apply to FRPS equation:

$$5.0 \times 10^{-6} \times W_{\max}^{4.5}$$

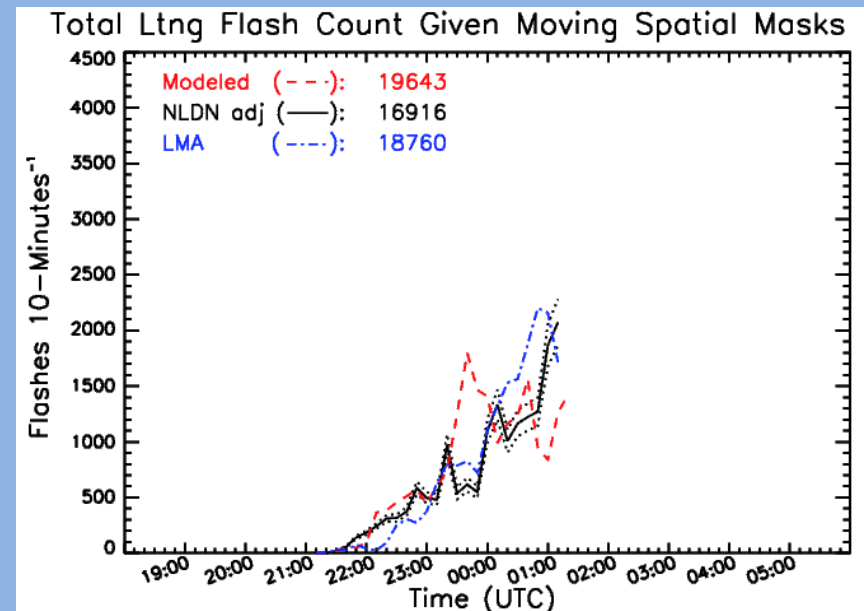
- Compared flash rate trends over the observed and model-simulated storm's lifetime
- Analyzed trace gas species (i.e., CO, NO_x, O₃) using model-simulated values and aircraft (DC-8 & GV) observations to:
 - Investigate NO production scenario
 - Compare inflow and outflow statistics
 - Create probability distribution function (PDF) plots in storm outflow



**Plots courtesy of M. Bela*

Model Flash Rates vs. Observations

- Model-simulated storm onset occurs 40 min (21:50-05:00 UTC) after observed storm (21:10-04:10 UTC)
- Model severely overestimated the simulated flash rates compared with observations
- Scaling the W_{\max} FRPS equation generates similar flash rates as observations
- Initial peak in model-simulated flashes (23:40 UTC) occurs earlier than observations (~01:30 UTC)



Note: Model-simulated flash rates shifted 40 min earlier to start with observed flashes (21:10). The model-simulated flash rates plotted above are scaled.

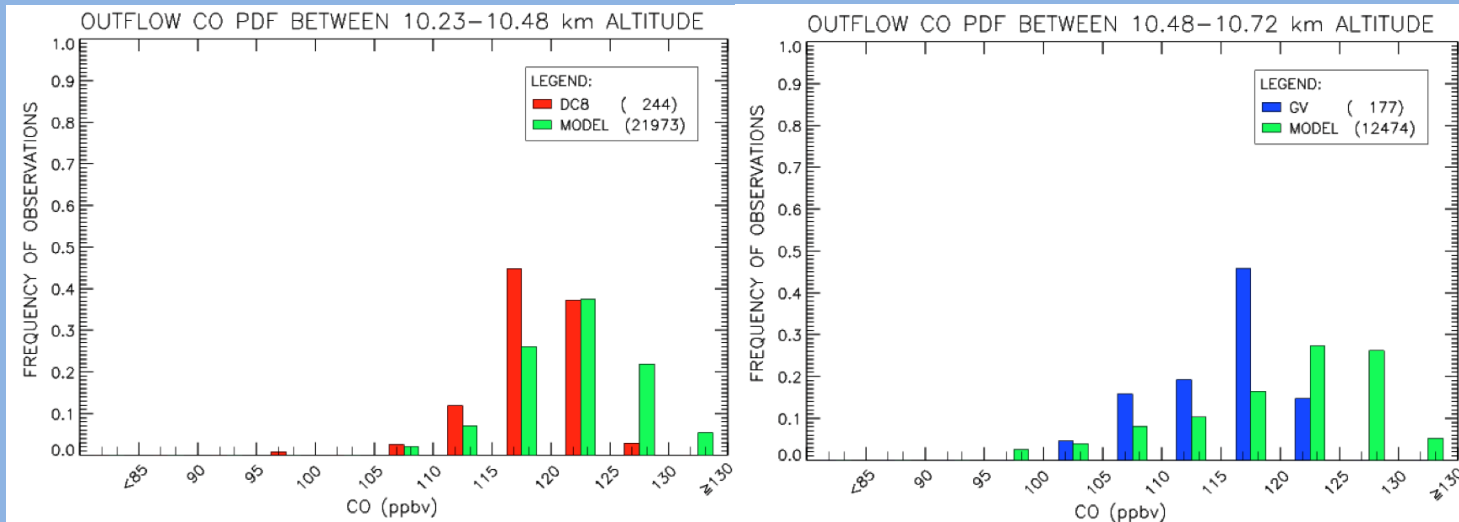
NO Production Scenario

- LNO_x production of 500 moles flash⁻¹ produced NO_x mixing ratios in anvil outflow a factor of four greater than observed by aircraft
- Reduced LNO_x production to 125 moles flash⁻¹ (*see table*):
 - Inflow NO_x larger in model possibly due to emissions
 - Outflow NO_x larger in model possibly due to strong vertical velocity

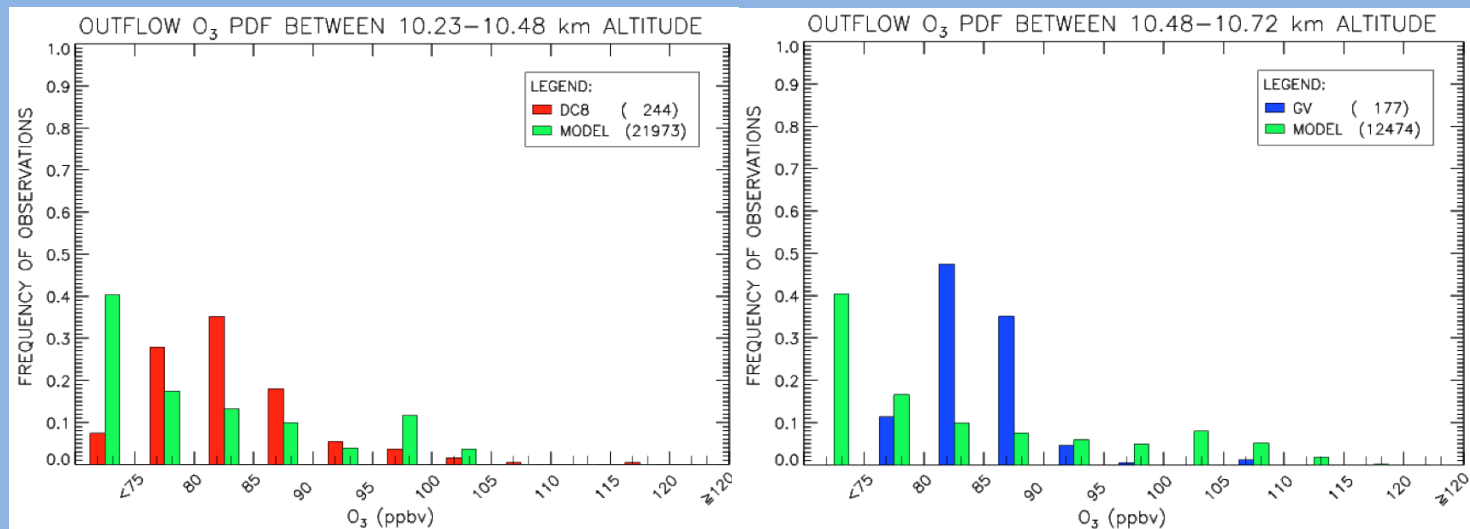
		CO (ppb)	O ₃ (ppb)	NO _x (ppb)
Outflow	Obs	115.2	85.1	0.798
	WRF-Chem	115.9	85.9	0.895
Inflow	Obs	132.8	54.8	0.399
	WRF-Chem	143.1	60.6	0.547

**Statistics represent mean values from 23:00-00:20 UTC (courtesy of M. Bela).*

Trace Gas PDFs in Storm Outflow

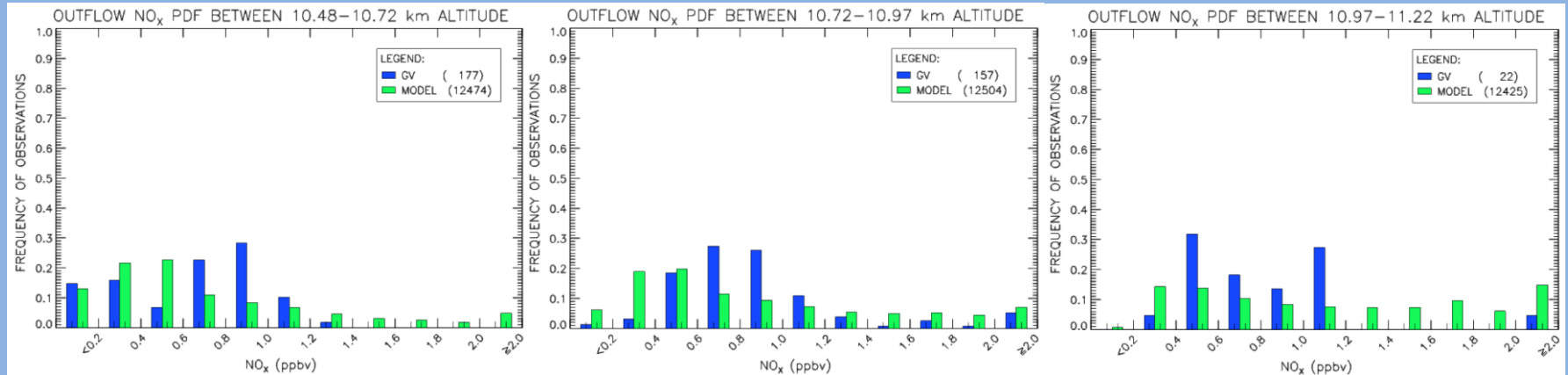


Model-simulated CO (*green*) peaks at higher values than observations



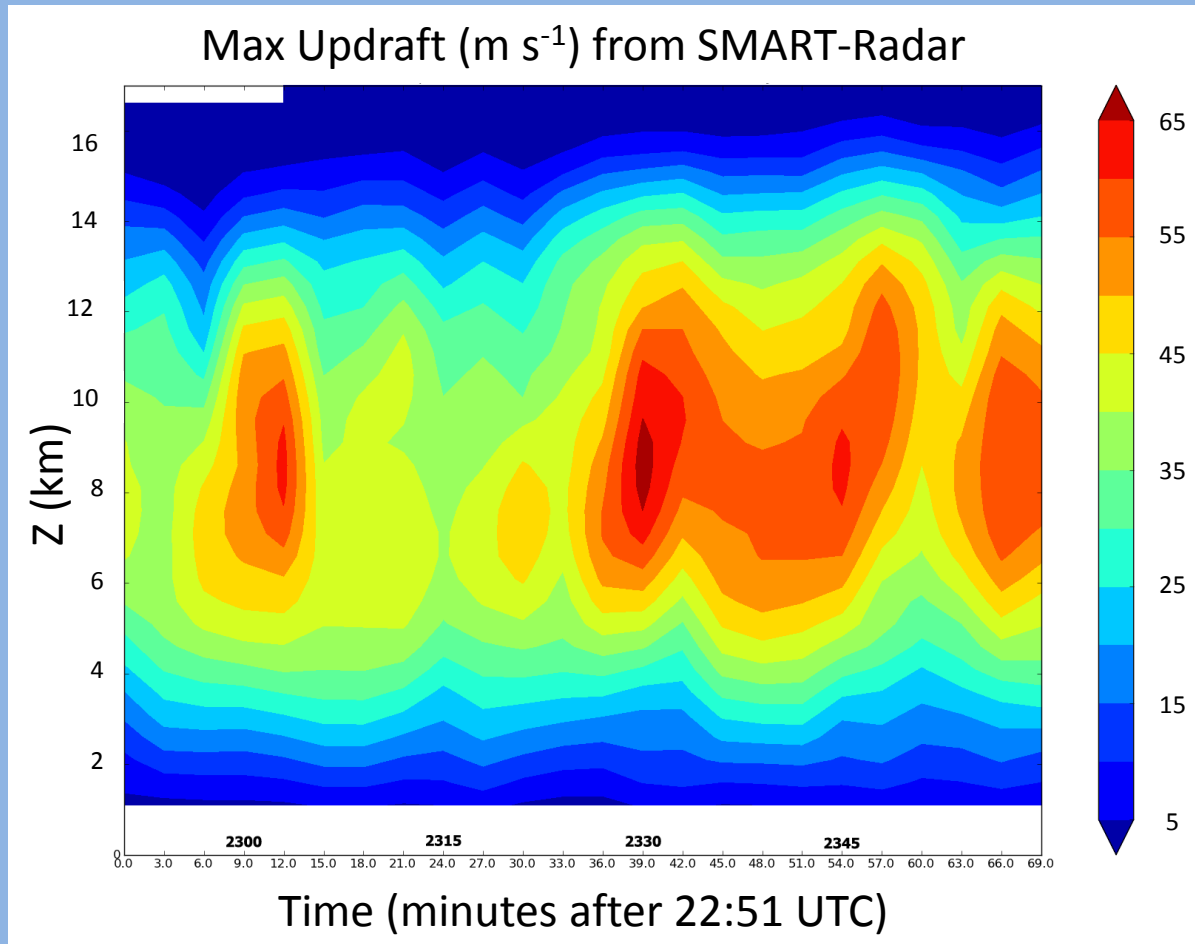
Model-simulated O₃ (*green*) peaks at lower values than observations

Trace Gas PDFs in Storm Outflow



- Aircraft measurements (*blue*) indicate the number of higher NO_x values start to slightly increase from 10.48-11.22 km
 - Influence from upper lightning channel peak at -45°C (10.5 km)
- Model-simulated NO_x (*green*) peaks at lower values than observations
 - Is model-simulated vertical velocity slightly stronger?
- Higher NO_x values observed by model (*green*) due to influence from upper lightning channel

Comparison of Storm Vertical Velocity

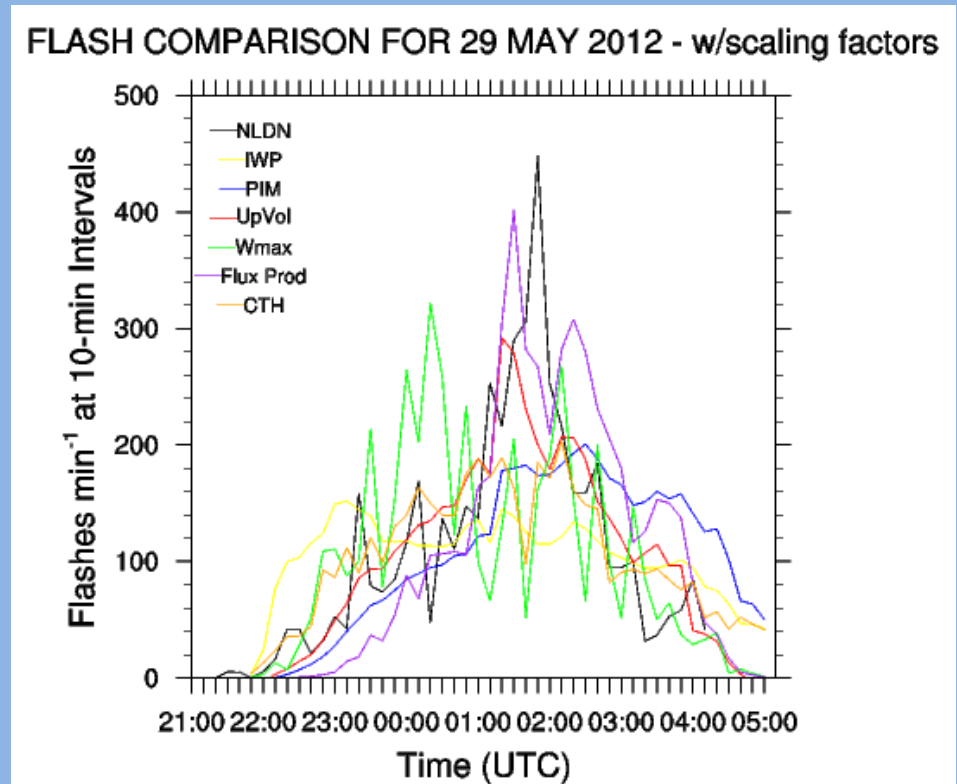


*Plot courtesy of M. Biggerstaff

- SMART-Radar data:
 - Complete record of 3 mobile radars between 22:51-00:00 UTC
 - Average $W_{\text{max}} \sim 49 \text{ m s}^{-1}$
- WRF output data (*not shown*):
 - Storm onset delayed 40 min (23:30-00:40 UTC)
 - Average model-simulated $W_{\text{max}} \sim 59 \text{ m s}^{-1}$

Conclusions

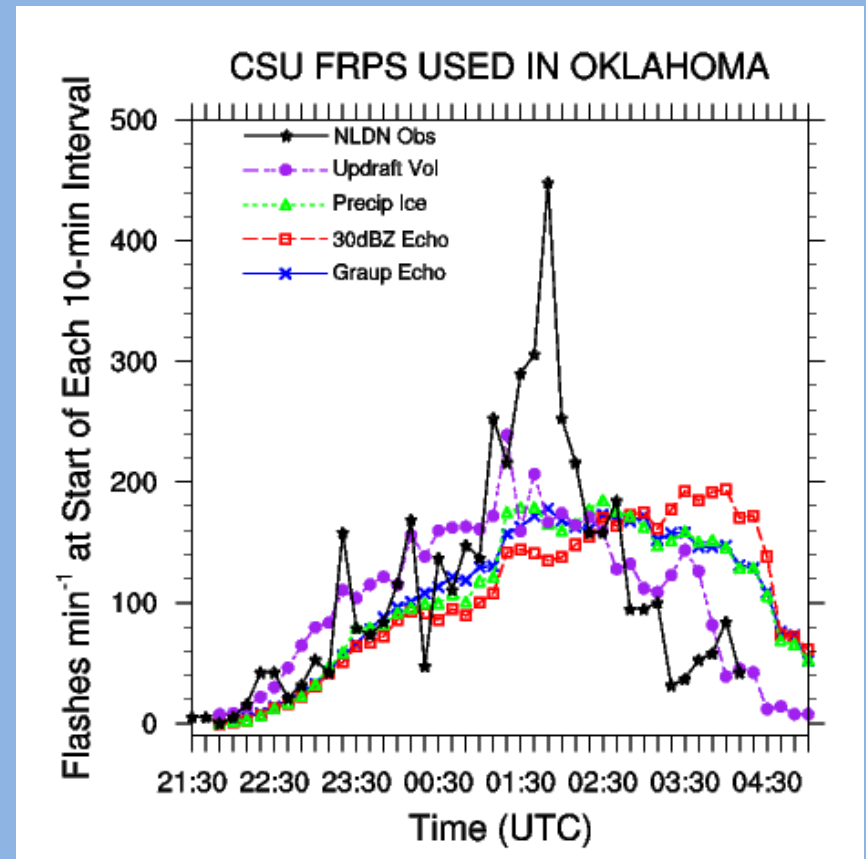
- A single model domain at fine resolution (1-km) produces a storm of roughly the same size as observed, however, the model-simulated:
 - Flashes must be scaled
 - W_{\max} is 1.2X stronger
- W_{\max} FRPS is not appropriate for the 29-30 May storm:
 - Flashes overestimated despite applying a scaling factor to the vertical velocities
- Slightly stronger model-simulated W_{\max} leads to the over prediction of trace gas transport shown in CO, NO_x, and O₃ PDFs
- Tentatively conclude LNO_x production is around 125 moles flash⁻¹
- Other FRPSs should be pursued, which:
 - Don't require significant scaling
 - Better follow observed flash rate trend
 - Examples include updraft volume and ice mass flux product



Note: The FRPS flash rate trends in the above plot are based on offline calculations and are adjusted with scaling factors.

Future Work

- Six FRPSs from CSU will be tested in the online model:
 - Updraft volume $> 15 \text{ m s}^{-1}$
 - Precipitating ice mass
 - 30-dBZ echo volume
 - Graupel echo volume
 - Area-height schemes based on graupel or dBZ
- Compare results of FRPSs with 1-min/1-km LMA data
- Investigate O_3 changes within the cloud and downwind of the storm



Note: The FRPS flash rate trends in the above plot are based on offline calculations and are adjusted with scaling factors.

Acknowledgements

- Regional NEXRAD level II data provided by Cameron Homeyer (NCAR)
- NLDN data collected by Vaisala, Inc. and archived by NASA MSFC



QUESTIONS?

Mean Values

	ppb		CO	O3	NOx	NO2
Outflow	Obs	Mean	115.2	85.1	0.79808	0.29233
		Std Dev	9.7	9.3	0.70721	0.36244
	WRF-Chem	Mean	115.9	85.9	0.89537	0.29245
		Std Dev	16.1	12.7	0.79960	0.23671
Inflow	Obs	Mean	132.8	54.8	0.39930	0.39574
		Std Dev	2.7	3.8	0.06889	0.06554
	WRF-Chem	Mean	143.1	60.6	0.54680	0.46221
		Std Dev	1.5	1.3	0.26098	0.21547
	ppb/ppb		CO	O3	NOx	NO2
Outflow	Obs	Mean	---	0.746	0.00665	0.00242
		Std Dev	---	0.127	0.00558	0.00294
	WRF-Chem	Mean	---	0.758	0.00723	0.00240
		Std Dev	---	0.160	0.00601	0.00183
Inflow	Obs	Mean	---	0.406	0.00298	0.00296
		Std Dev	---	0.022	0.00052	0.00050
	WRF-Chem	Mean	---	0.424	0.00381	0.00322
		Std Dev	---	0.009	0.00171	0.00142
Outflow	Obs		0.867	1.839	2.235	0.817
/Inflow	WRF-Chem		0.810	1.789	1.900	0.745

*Expanded table from slide 8, where statistics represent mean values from 23:00-00:20 UTC (courtesy of M. Bela). Top half of table represents mixing ratios. Bottom half represents CO ratios.